Status report of the ANTARES project

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The ANTARES project aims at the construction of an underwater neutrino telescope at the scale of 0.1 km^2 2400 m deep in the Mediterranean Sea. After a 4-year R&D program, the ANTARES project has entered the construction phase which will be concluded by the end of 2004. The current status of the project is reported.

1. The ANTARES project

Neutrino telescopes of huge dimensions can investigate the far Universe and the Very High Energy (VHE) cosmic ray sources. Neutrinos are unique 'probes' to investigate regions at larger distances than 50 Mpc, because they are weakly interacting and point backwards to their source. Large neutrino telescopes are designed to detect the Cherenkov light emitted by charged particles in deep water/ice using an array of phototubes (PMTs) enclosed in high pressure resistant glass spheres called optical modules (OM). Upward going muons produced by neutrinos having crossed through the Earth, are recognized as products of ν interactions in the instrumented region or close to it. Neutrino telescopes are expected to measure the muon direction and energy, while distinguishing the neutrino signal from the atmospheric muon background, which is orders of magnitude larger. PMT pulse times and amplitudes allow us to calculate these quantities.

The ANTARES (Astronomy with a Neutrino Telescope and Abyss environmental RESearch) project [1], is complementary to already existing experiments, such as AMANDA [2] and Lake Baikal [3], in covering the whole sky looking for neutrinos of astrophysical origin. The ANTARES collaboration involves physicists and astrophysicists, sea science experts and engineers from France, Italy, the Netherlands, Russia, Spain and the United Kingdom. The project started in 1996. During a 4 year R&D phase, extensive campaigns of measurements of environmental parameters have lead to the selection of the detector site located 40 km off the Toulon coast (South France) at a depth of 2400 m. Thanks to the rotation of the Earth, this location (42° 50'N, 6° 10'E) has an efficient sky coverage of about 3.5π sr, with approximately a 0.5π sr overlap with AMANDA, and allows to survey the Galactic Center, not accessible to AMANDA.

2. The R&D phase

Since 1996, several measurement systems have been designed and operated in order to locate the site where the deployment of the detector is possible and to study the sea-water properties which largely determine the design of the detector.

Surveys have qualified the sea bed for detector deployment; observed currents, on average ~ 6 cm/s with maximum peaks of 19 cm/s, are taken into account to allow long term continuous operation. When exposed to sea water, optical module surfaces are fouled by living organisms and by sediments. These processes reduce light collection efficiency. Results from about 8 months of measurements with a system of PIN diodes illuminated by a blue LED at angles between 50° to 90° from upward vertical, have shown that at 90° fouling induces a light loss of about 2 % per year. Consequently, ANTARES PMTs will be oriented downwards. Water transparency determines light detection efficiency, while the amount of scattered photons affects reconstruction and hence pointing capabilities. The photon arrival time distributions for a pulsed isotropic LED source at wave-

lengths of 370 nm (UV) and 470 nm (blue) have been measured at 2 different distances of a 1" PMT from the source (24 m and 44 m). These distributions are used in simulations including the PMT angular response to develop and test reconstruction techniques, described in detail in [4]. For a distance of 24 m, 95% of the emitted photons are collected by the detector within 10 ns (30 ns) for blue (UV) light. It is found that for blue light the absorption length is ~ 55 m and the effective scattering length (the scattering length divided by $1 - \langle \cos\theta \rangle$, where θ is the scattering angle) is in the 300 m range. The scattering contribution is negligible in sea water compared to ice.

Trigger logic and electronics, track reconstruction and background rejection must take into account the presence of background light due to the β-decay of ^{40}K present in sea water. This light produces an almost constant counting rate of about 60 kHz on a 10 inch PMT (much higher than the background rate for AMANDA at the South Pole). Moreover, short bioluminescence bursts of MHz counting rate with few ms rise-time over a few seconds have been measured. These induce on average less than 5% dead time on PMTs with negligible correlation between storeys.

From Nov. 1999 to June 2000, a demonstrator string was deployed at a depth of 1100 m and connected to shore with a 37-km electro-optical cable. The string had a structure different from the current design, containing couples of glass spheres separated by 15 m. Near the bottom 7 OMs were equipped with PMTs oriented horizontally. More than 50000 of 7-fold coincidences were recorded and zenith angles were reconstructed using recorded times and amplitudes. We reproduced the shape of the zenith angular distribution of atmospheric muons reasonably well, in spite of the single string and the small number of PMTs. After reconstruction, the simulation which is compared to the data includes a $\sim 50\%$ contribution of multiple muons (due to the shallow depth of the string).

The demonstrator string allowed us to test the ANTARES relative and absolute positioning with a system of acoustic rangemeters, compasses and tiltmeters. Relative distances between 2 elements were measured with 5 cm accuracy while absolute positioning was obtained with ~ 1 m accuracy.

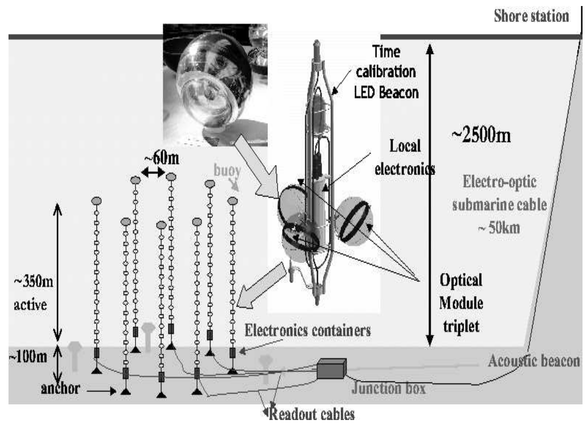

Figure 1. Schematic view of the detector showing an OM and some details of a storey enlarged.

3. Detector design and physics studies

The final detector design (Fig. 1) was defined after the R&D environmental and electronics studies and after simulations of the detector response, given cost constraints. Ten strings, holding 90 PMTs each, made by mechanically strong electro-optical cables and anchored at the sea bed will be deployed. Strings, kept taut by buoys at the top, will be separated by roughly 60 m. Each string contains 30 storeys separated by 12 m. Each storey is equipped with 3 OMs oriented outwards at 45° downwards. The 10" Hamamatsu R7081-20 PMTs in the OMs are sensitive to single photons with transit time spread < 3 ns (FWHM). The electronics chain has a timing precision of ~ 1 ns. Signals are digitized, then read out via optical fibers in cables. A submarine will connect the cables from individual strings to a junction box at the end of an electro-optical cable sending signals to a shore base where data are recorded. The ~ 40 km long cable has been recently successfully deployed. An extra-string will be devoted to environmental parameter measurements. The possibility to extend the detector up to 14 strings is considered.

The ANTARES scientific program is mainly devoted to the detection of neutrinos of astrophysical origin with energies above 10 GeV. Extragalactic and galactic objects could be emitting neutrinos as a consequence of hadronic production mechanisms alternative to the electromagnetic processes.

Parameters to qualify a neutrino telescope are its effective area, which includes reconstruction and selection efficiency [1], the angular resolution and the energy resolution. Simulation results show that the effective area exceeds the geometrical surface in the high energy region of interest even after strict selections (see Fig. 2). The neutrino pointing resolution and the intrinsic angular resolution of the telescope, defined as the median angular separation between the 'true' and the reconstructed muon track, has been studied by simulations. For reconstructed events the angular resolution improves with energy. Above 10 TeV, the pointing resolution is found to be within $\sim 0.2°$, in spite of light scattering effects.

Below 100 GeV, neutrino energy is inferred from muon range in the detector, while at energies > 1 TeV an energy estimator based on the PMT charge amplitudes currently allows a confidence interval (68% C.L.) on the measured energy E between $\sim E/3$ and $\sim 3E$. We are still working on rejection algorithms to suppress atmospheric neutrinos based on the deduced energy. Simulations show that by imposing a $\sim$ 10 TeV cut, 20/150 events/yr are selected using single AGN [5]/ diffuse AGN [6] fluxes with a background of $\sim$ 10 atmospheric neutrino events/year.

Preliminary results on neutralino searches from the core of the Sun and from the Galactic Center, where these particles could be trapped if they are the dark matter in the Galaxy, have been shown in [7]. The ANTARES sensitivity may be better than current experiments, taking into account the different energy thresholds. The algorithms developed for the oscillation studies, also used for dark matter searches, show that ANTARES is expected to reach down to an energy threshold of 10 GeV (thanks to the inclusion of single-string reconstructed events) with a median angular error of 2.6° below 100 GeV.

[1] At high energies the number of 'volume' events with the vertex inside the instrumented region is relatively small.

Studies on the ANTARES performance for neutrino oscillations show that Δm^2 can be measured throughout the region allowed by Super-Kamiokande with a precision of about 30% in 3 years. (For maximum mixing, the region $\Delta m^2 \sim 3 \cdot 10^{-4} - 6 \cdot 10^{-1}$ eV^2 could be excluded with 90% C.L.). The observables used are the zenith angle θ and E/L (L is the baseline which is almost proportional to $\cos\theta$) for 4000 upgoing muons/year. Backgrounds and systematic errors are under study.

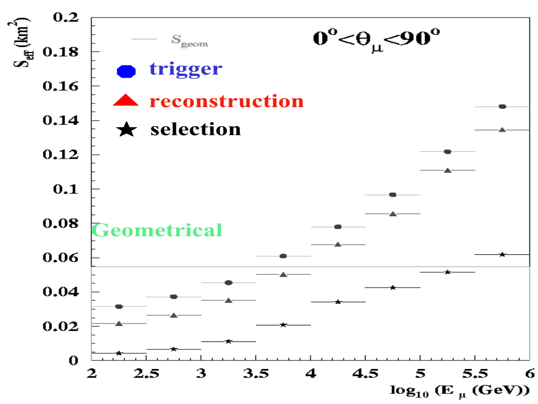

Figure 2. Effective area as a function of simulated upward-going muon energy.

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